

## Space Shuttle Partial Stack Rollout Test Analytical Correlation In Support Of Fatigue Load Development

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### ABSTRACT

A rollout test with only the Solid Rocket Boosters was conducted in November 2003 to gather structural dynamic response data of the transportation environment from the Vehicle Assembly Building to the Launch Pad. The data was acquired to develop and validate analytical methods used to predict rollout Orbiter fatigue load spectra. Earlier predictions computed by a base drive approach with only 5 input drive degrees-of-freedom raised questions that commissioned the partial stack test. Not only was there a concern because of the input degree-of-freedom omission due to measurement limitations, but there was also a concern with the implementation of the "large mass" itself. Three methods were evaluated with the partial stack test data. The analytical correlations to measured strain derived SRB base loads and accelerations showed the earlier 5 degree-of-freedom base drive approach to yield the most conservative results for all quantities monitored except the SRB base moment about the axis in which the input drive was missing. This non-conservative shortcoming led to a recommendation to use either the 6 degree-of-freedom base drive or the 12 degree-of-freedom Craig-Bampton boundary drive methods whose results did not substantially differ.

### INTRODUCTION

The rollout of the Space Shuttle Vehicle (SSV) from the Vertical Assembly Building (VAB) to the launch pad is a slow, exacting process that reaches maximum speeds of only 0.9 miles per hour and takes approximately 6 hours to cover the 3 to 4 mile distance. While not often thought of as a "dynamic" engineering venue, the ride to the pad is anything but discounted. The "crawler-way" itself is a unique river rock surfaced road bed that is prepared for every SSV pass. The 3 million pound SSV is cantilevered from the base of its left and right Solid Rocket Boosters (SRBs) to the 9 million pound Mobile Launch Platform (MLP). The SSV consists of three Elements: the SRBs, the External Tank (ET), and the Orbiter. Both the 150 foot tall SRBs and the Orbiter attach to the ET which rises an additional 35 feet above the SRBs. The MLP is attached at four locations to the 6 million pound Crawler Transporter (CT) that drives the assembly to the pad. The CT to MLP interface is approximately 20 feet above the road bed, and the MLP to SRB interface is at 45 feet. The CT to MLP attachment locations are arranged in a 90 foot square, centered above the CT "propulsion trucks" at each of the CT's four corners. The interface schema is fairly complex with each corner attachment possessing a unique load carrying capability such that there is vertical continuity at each with only four additional lateral translational components distributed among them. Each corner attachment also includes four pressurized "JEL" cylinders for jacking, equalizing, and leveling. The propulsion trucks contain a five gear and pinion system that transfer the power to the tread belt sprockets that drive dual belts, each fitted with fifty-seven, 2,200 pound, steel shoe treads. This assortment of gear meshing, shaft rotation, and shoe impact effects supply an environment rich in narrowband, harmonic content to the MLP that in turn transfers it to the base of the receptive SSV with overlapping modal frequencies.

Concern with the potential of this structural dynamic confluence occurred early in the SSV program. A rollout environment characterization was conducted in 1979 prior to the STS-1 mission with 19 dynamic acceleration measurements recorded on the Space Shuttle Facilities Verification Vehicle (FVV), also known as the Pathfinder Vehicle, for CT speeds from 0.10 through 1.0 miles per hour (MPH) [1]. For the nominal rollout speed of 0.90 MPH, peak accelerations on the order of 0.10 "g" were observed on the Orbiter tail and wing, with half these

levels at the SRB tip. A 2.9 Hz dominant frequency was noted. In general response increased with speed. It was concluded that "there do not appear to be any adverse dynamic response concerns from the Crawler Transporter forcing functions". Apparently due to this relatively benign characterization, no rollout loads spectra were developed to address structural life at that time, however load cases were generated to support the completeness of structural design from a strength perspective.

Two decades later as part of the Hurricane Preparedness Program, SRB hold down post (HDP) strains were recorded during rollout on STS-103 and STS-99 in 1999. The HDPs are the SRB's interface to the MLP with four HDPs per SRB bolted to the MLP. Although the measured load magnitudes were in fact benign compared to design limits, the levels combined with the number cycles suggested that further structural life assessments be conducted [2]. Measurements continued for 11 additional missions through STS-109 in early 2002 that included 6 channels of MLP accelerations in addition to the SRB HDP strains. The accelerations were limited to two center line MLP locations at the front and aft ends of the lower deck. This data was used to excite a structural finite element model of the MLP/SSV assembly to compute SRB, ET, and Orbiter structural response loads from which rollout spectra were then generated to assess the SSV's structural life. Reference 2 documents this process and the release of rollout spectra for the Orbiter and SRB Elements in January 2003.

What was anticipated to be simply an exercise for completeness, became a program level concern as the Orbiter Element reported a significant decrease in life due to the January 2003 spectra. With the spectra report itself casting concerns with the approach, stating that "some loads conditions proved to be unstable as the base-drive methodology caused overly-excited responses" when compared to the SRB base loads derived from the HDP measured strains, an overall program level review ensued. The review ultimately recommended that testing be conducted to evaluate the analytical methodologies, and the effects of the 5 degree-of-freedom (DOF) base drive input restriction that omitted the "roll" moment about the CT/MLP because of the co-linear located measurements. In September of 2003, the program authorized near term tests without the ET and Orbiter, a.k.a. Partial Stack Tests, and subsequent Full Stack Tests upon return to flight. The Partial Stack Tests were to include two configurations; one with the SRBs on the CT/MLP, and one with the CT/MLP alone [3]. In November 2003 the Partial Stack Test was conducted with the CT/MLP/SRB configuration shown in Figure 1. 111 channels of acceleration data were recorded along with 80 channels of SRB HDP strains, 8 channels of JEL cylinder pressures, and a channel for CT speed and one for ambient wind. Data was collected for over ten hours over two days in ten minute or greater segments. The segments captured transient and steady state operations over various road bed conditions. Transient segments included acceleration and deceleration from and to "rest". Steady state segments included variation in CT speeds from 0.5 to 0.9 miles per hour in 0.1 mile per hour increments on straight and turning crawler way sections. Steady state data was also taken at rest for wind only assessments.

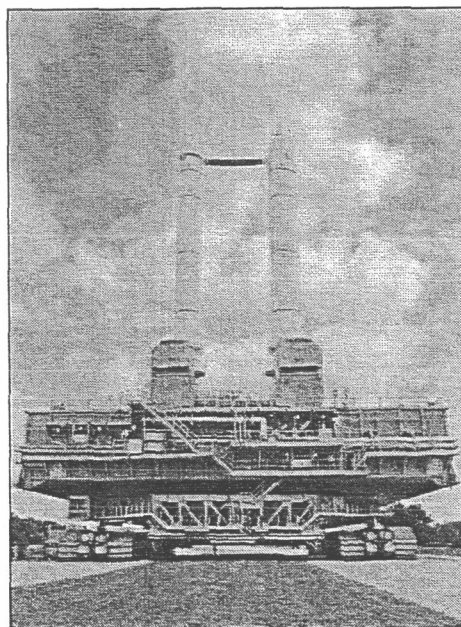


Figure 1: Partial Stack Rollout Test Configuration